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MOTION OF A DROP OF ALKALI METAL IN A CURRENT OF VAPOR WITH CONDENSATION

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MOTION OF A DROP OF ALKALI METAL IN A CURRENT OF VAPOR WITH CONDENSATION

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ABSTRACT: The time-dependence of the velocity of a drop of alkali metal, injected into a saturated moving vapor, is considered. A difference of 0.5% between drop velocity with and without consideration of condensation effects is found.

A theoretical study of the growth of a single drop of alkali metal with condensation upon it of a saturated vapor, in the absence of relative motion of the phases, was described in [1]. The results of the latter paper are used in the present article for consideration of the same drop relative to the vapor, with an explanation of the role of the dynamic effect of the condensation process. /801

Statement of the Problem and the Basic Equation

A spherical drop with radius r_0 and temperature T_0 is injected at a velocity v_0 into a vapor moving at a constant velocity $v_{vap} > v_0$. The vapor is pure and saturated, with a temperature in excess of the initial temperature of the drop, so that condensation takes place. The problem consists in determining the dependence of the velocity of the drop (v_{drop}) on time (τ).

According to [2], deformation of the drop may be disregarded. In the range of Reynolds numbers in question, we can use the coefficient of aerodynamic resistance of a solid sphere in the form $12.5\ \mathrm{Re}^{-0.5}$. It is assumed that condensation takes place in a thin boundary layer, uniformly over the entire surface of the sphere. Outside this layer, the leading hemisphere is potentially streamlined with a known distribution of velocities [3], while on the trailing hemisphere (due to the stripping away of the vortices) the velocity of the vapor relative to the drop is equal to zero.

The movement of the drop (with a simultaneous increase in its mass) is described by the Meshcherskiy equation [4], which has the following form in dimensionless variables:

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*Numbers in the margin indicate pagination in the foreign text.

$$x\frac{du}{dt} = 3.31\rho(1 - u)^{\frac{3}{2}} + 1.5(1 - u)\frac{dx}{dt}, \qquad (1)$$

where

$$x = \frac{r}{r_0};\ u = \frac{v_{drop}}{v_{vap}};\ t = \frac{\tau}{\tau_0};\ \tau_0 = r_0\frac{\sqrt{r_0}}{v_{vap}v_{vap}};\ \rho = \frac{\rho_{vap}}{\rho_{drop}}.$$

The law of the change in drop radius is determined by the intensity of the condensation of vapor on its surface and, according to [1], is expressed by the following relationships:

in segment $0 \leq t \leq t^*$:[1]

$$x = 1 + \frac{\kappa}{A_2}Bt, \qquad (2)$$

and in segment $t^* < t < +\infty$:

$$x = \frac{1}{c_1}(\lambda - \gamma c_2 e^{-c_1 Bt}), \qquad (3)$$

where

$$B = \frac{\tau_0}{r_0}\sqrt{\frac{P_{vap}}{\rho_{drop}}} = \text{const}.$$

Substituting (2) and (3) into (1), the latter is written as follows:

in segment $0 \leq t \leq t^*$:

$$(1 + at)\frac{du}{dt} = b(1 - u)^{3/2} + 1.5a(1 - u) \qquad (4)$$

and in segment $t^* < t < +\infty$:

$$(D_1 - D_2 e^{-D_3 t})\frac{du}{dt} = b(1 - u)^{3/2} + D_4 e^{-D_3 t}(1 - u), \qquad (5)$$

where

$$a = \frac{\varkappa}{A_2}B;\quad b = 3.31\rho;\quad D_1 = \frac{\lambda}{c_1};\quad D_2 = \frac{\gamma}{c_1}c_2;\quad D_3 = c_1 B;\quad D_4 = 1.5\gamma c_2 B.$$

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[1]The value of t^* with an accuracy up to factor B is equal to t^* in [3].

Integration of (4) in segment $0 \leq t \leq t^*$ gives /802

$$u = 1 - \frac{1}{\left[\left(b/1.5a + \frac{1}{\sqrt{1-u_0}}\right)(1+at)^{3/4} - b/1.5a\right]^2} \quad (6)$$

where $u_0 = v_0/v_{vap}$.

Nonlinear equation (5) is not integrated directly. An estimate of the behavior of the first and second terms on the right-hand side shows that (beginning with a certain $t = t^{**}$) the value of the second term can be disregarded in comparison with the first, and (5) can be replaced by an equation of the form

$$D_1 \frac{du}{dt} = b(1-u)^{3/2}. \quad (7)$$

As a result of integration of the latter in the interval $t^{**} < t$, we have:

$$u = 1 - \frac{1}{\left[1/\sqrt{1-u^{**}} + \frac{b}{2D_1}(t - t^{**})\right]^2}. \quad (8)$$

In carrying out the practical calculations, integration of (5) for the segment $t^* < t < t^{**}$ is accomplished numerically (for example, by the Eulerian method). The calculated formula in this case has the form

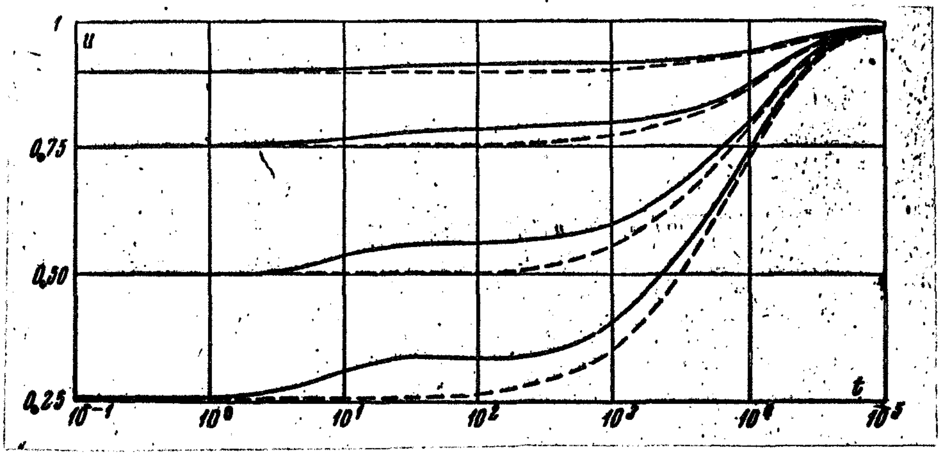
$$u_n = u_{n-1} + \frac{b(1-u_{n-1})^{3/2} + D_4 e^{-D_3 t_{n-1}}(1-u_{n-1})}{D_1 - D_2 e^{-D_3 t_{n-1}}}(t_n - t_{n-1}), \quad (9)$$

where the subscript n corresponds to the number of the integration step.

Evaluation of the Results

The figure shows the relationship $u(t)$ for the case of the movement of a drop with $r_0 = 10^{-4}$ m and $T_0 = 400°K$ with $T_{vap} = 800°K$, $v_{vap} = 100$ m/sec and $v_0 = 25, 50, 75, 90$ m/sec, obtained in accordance with (6), (8) and (9).

The first term on the right-hand side of (1) represents the force of the aerodynamic effect of the vapor on the drop, while the second term represents the reactive force produced by the joining of the particles. To estimate the contribution of both forces to



the acceleration of the drop, it is necessary to obtain an expression for the velocity of the drop without condensation. Integration of the equation of motion for a drop of constant mass gives

$$u = 1 - \frac{1}{\left(\frac{1}{\sqrt{1-u_0}} + \frac{b}{2}t\right)^2}. \qquad (10)$$

Relationship (10) is represented in the figure by a dashed line. As is evident, the difference between the solid and dashed curves increases with time and at $u_0 = 0.25$, for example, reaches 28%. In addition, the degree of deviation is inversely proportional to the initial velocity of the drop. Thus, condensation considerably speeds up the process of acceleration of the drop. Moreover, in the segment $0 \leq t \leq t^*$ it plays a critical role in acceleration. In fact, the solution of (1) with the aerodynamic term omitted has the form /803

$$\bar{u} = 1 - \frac{1 - u_0}{(1 + at)^{2/3}}. \qquad (11)$$

The table shows the results of comparing the velocity of the drop u and its velocity without consideration of the dynamic effect of the vapor $\bar{u}$ in this segment. The difference does not exceed 0.5%, which indicates the prevailing effect of the reactive force of condensation in the segment $0 \leq t \leq t^*$. The effect of this force weakens in the course of time, tending toward zero at the limit.

u_0	t	u	$\tilde{u}$	$\Delta u = u - \tilde{u}$	$(\Delta u/u)\cdot 100\%$
0.25	0.5	0.2527	0.2527	0	0
	1	0.2555	0.2554	0.0001	0.039
	1.5	0.2582	0.2580	0.0002	0.077
	2	0.2609	0.2607	0.0002	0.077
	2.5	0.2636	0.2633	0.0003	0.1138
	3	0.2662	0.2659	0.0003	0.1126
	6	0.2827	0.2814	0.0013	0.459
0.5	0.5	0.5018	0.5018	0	0
	1	0.5036	0.5036	0	0
	1.5	0.5054	0.5053	0.0001	0.0195
	2	0.5072	0.5071	0.0001	0.0197
	2.5	0.5090	0.5089	0.0001	0.0196
	3	0.5108	0.5106	0.0002	0.0391
	6	0.5220	0.5209	0.0011	0.21
0.75	0.5	0.7509	0.7509	0	0
	1	0.7518	0.7518	0	0
	1.5	0.7527	0.7527	0	0
	2	0.7536	0.7536	0	0
	2.5	0.7549	0.7544	0.0005	0.066
	3	0.7554	0.7553	0.0001	0.013
	6	0.7608	0.7605	0.0003	0.039
0.9	0.5	0.9004	0.9004	0	0
	1	0.9007	0.9007	0	0
	1.5	0.9011	0.9011	0	0
	2	0.9014	0.9014	0	0
	2.5	0.9018	0.9018	0	0
	3	0.9021	0.9021	0	0
	6	0.9043	0.9042	0.0001	0.011

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